THE ROLE OF NUCLEAR POWER IN U.S. ENERGY SUPPLY

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ABSTRACT

Commercial nuclear reactors provide almost one-fifth of U. S. electricity supply. This paper describes the costs and performance of these plants and provides projections of their contribution through 2020. The economics and engineering issues that determine if plants will retire before their operating licenses expire or if plants will seek license renewal are presented. Environmental considerations that could alter outcomes are also addressed including impacts on fossil fuel consumption and carbon emissions. The projections are drawn from the Energy Information Administration reports *Annual Energy Outlook 1999* and *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity.*

BACKGROUND

Nuclear power plants provided 18 percent of the electricity generated in the United States in 1997. It is the second largest contributor behind coal which provides about 53 percent. Oil and natural-gas fired plants contribute about 17 percent and renewable sources (including hydroelectric) make up the balance. However, the role of nuclear power is expected to diminish in the future as plants begin to retire and no new capacity is built. This is likely to occur even though the plants currently operating have shown remarkable improvement in operating performance over the last several years. Since 1985 the performance of nuclear plants as measured by the capacity factor[1] has improved from 58 percent to 77.4 percent in 1995 before dropping back to 70.8 percent in 1997.[2] These improvements reflect a coordinated industry wide effort[3] to reduce incidents where plants are taken out of service (forced outages) and to increase periods between refueling outages. At the same time efforts have been made to reduce operating costs of plants to make them competitive with other generator types in response to the opening of markets for generation services to competition.

Nuclear plants have operating licenses that expire after 40 years. However, to this date no plants have actually achieved this period of service. Several plants have retired early (after operating 17 to 35 years) because of combinations of high operating costs, performance problems, and needs for significant capital investment to replace components such as steam generators.

In order to determine what role nuclear power will have in the future it is necessary to consider the remaining lives for the balance of plants currently in service[4]. To that end, it has been assumed that if it is economic to continue to operate a nuclear plant an age related investment of about $150 per kilowatt (about $150 million for a typical unit) will be required after 30 years of operation for plants with older designs (about one half of the existing capacity) in order to permit them to continue generating for 10 additional years.[5] Units with newer designs are estimated to require somewhat

[1]Capacity factor is the ratio of the actual electricity produced by a plant divided by the electricity that could have been produced at continuous full-power operation over the entire year.

[2]Energy Information Administration, *Annual Energy Review 1997,* DOE/EIA-0384(97) (Washington, DC, July1998).

[3]The nuclear industry formed a collaborative organization called the Institute for Nuclear Power Operations to address comprehensive improvements in the operation of nuclear generators.

[4]The Energy Information Administration produces projections of U.S. energy markets published in the *Annual Energy Outlook 1999.* The report has projections for nuclear power through 2020. See Energy Information Administration, *Annual Energy Outlook 1999,* DOE/EIA-0383(99) (Washington, DC, December 1998).

[5]Plants that have already incurred capital expenditures for steam system replacements are assumed to operate for 40 years with no additional investment.

lower costs. This expenditure is intended to be equivalent to the cost that would be associated with any of several needs such as a one time investment to replace aging equipment (steam generators), a series of investments to fix age related degradation, increases in operating costs, or costs associated with decreased performance. This investment is compared with the cost of building and operating the lowest cost new plant (typically a natural gas-fired combined-cycle unit) over the same 10 year period. If the cost of the investment for the nuclear plant is less than the alternative, it is assumed to remain in service. If the alternative is less expensive, then the nuclear plant is retired after 30 years of operation. Using these assumptions results in projections of almost 24 gigawatts of nuclear capacity being retired prematurely. This is in addition to the almost 7 gigawatts of capacity that has already been retired. A substantial portion of this capacity is located in the Northeastern United States and is expected to retire between 2000 and 2006. The retired capacity in the Northeast is almost 11 percent of total capacity available in that region.

A similar method is used to determine if it is economic to apply for license renewal and operate plants for an additional 20 years. Nuclear plants are estimated to face an investment of $250 per kilowatt (about $250 million for a typical one gigawatt unit) after 40 years of operation to refurbish aging components. This investment is compared with the lowest cost new plant alternative evaluated over the same 20 years that the nuclear plant would operate. If the nuclear plant is the lowest cost option, it is projected to continue to operate. EIA projects that it would be economic to extend the operating licenses for six gigawatts of capacity[6].

PROJECTIONS

Given the retirements (determined by the economic test at 30 years and by the expiration of operating licenses[7]) and license renewals discussed previously, nuclear generation is projected to decline over time. Nuclear generation is projected to drop from 629 to 359 billion kilowatt hours from 1997 to 2020 in the reference case[8]. Most of this decrease is expected to occur after 2010 when plants installed in the 1970's which don't pass the license renewal test begin to retire at the end of their operating licenses. As a result of lower output, the share of nuclear generation is expected to decline from18 percent in 1997 to 7 percent in 2020. By 2020, renewable sources (including hydroelectric generation) account for more generation than nuclear plants. Nuclear generation drops from the second largest provider in 1997 to fourth in 2020 behind coal, natural gas, and renewable sources.

Because there is considerable uncertainty related to the investments required to allow plants to operate for 40 years, two alternative cases with higher and lower cost assumptions were analyzed. In the higher cost case the $150 per kilowatt investment to allow a plant to continue operations after 30 years was assumed for all reactors including the newer design units. This assumption captures the possibility of plant degradation and fuel storage costs beyond those assumed in the reference case. In this case an additional 16 gigawatts are retired by 2020. The retired nuclear capacity is replaced with new coal-fired steam units (30 percent) and new natural gas-fired combined cycle units (28 percent) and combustion turbines (42 percent). The consumption of coal and natural gas are higher in 2020 by about 0.4 quadrillion Btu for each fuel or 2 and 5 percent, respectively. Because more fossil fuels are consumed, the emissions of carbon are 17 million metric tons higher than the 745.5 million metric tons in the reference case in 2020.

In the more optimistic case it was assumed that plants could operate beyond 40 years without incurring a major capital expenditure at either 30 years or 40 years. This assumption is made to determine the impacts under the most optimistic outcome. These assumptions result in higher nuclear generation which causes fossil-fired additions to decline by 28 gigawatts and renewable sources to decrease by almost 1 gigawatt compared with the reference case in 2020. Carbon emissions are 30 million metric tons less than in the reference case in 2020. This reduction represents about 15 percent of the growth in carbon emissions from electricity production between 1997 and 2020. This means that 15 percent of the increase in carbon emissions could be offset if nuclear plants continued to operate beyond 40 years.

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[6] In 1998 Baltimore Gas and Electric, owner of Calvert Cliffs, and Duke Power, owner of Oconee, applied to the Nuclear Regulatory Commission to renew the licenses for those plants.

[7] There are currently no announcements for early retirement of plants beyond those that have already been shutdown.

[8] Energy Information Administration, *Annual Energy Outlook 1999*, DOE/EIA-0383(99) (Washington, DC, December 1998). The report is available at http://www.eia.doe.gov.

The availability of a permanent storage site for high level waste is an issue important to the future of nuclear power. The lack of a permanent storage site is a major factor in the decision to build nuclear capacity. The requirements for spent fuel disposal vary slightly for the cases described above. In addition to the 35 thousand metric tons of spent fuel already accumulated, an additional 39 to 43 thousand metric tons would be generated by 2020 for the cases analyzed, more than doubling current inventories.

Beyond the waste storage problem there are also high investment requirements for new nuclear plants that make them non-competitive with new coal-fired steam plants and natural gas-fired combined cycle units through 2020. Table 1 provides the cost information for a coal-fired steam plant, a natural gas combined-cycle unit, and a nuclear unit. The nuclear cost assumes that plants can be built at guaranteed prices[9]. The table shows that the capital portion of the cost of the nuclear plant is higher than the other technologies. Even though nuclear plants have a very low fuel cost compared with the other types, the difference is not sufficient to overcome the differences in capital costs. As a result the total cost of producing electricity from a new nuclear unit is higher than for the other generating types.

Although there are significant impediments to construction, it is useful to examine the impacts that existing nuclear power plants could have on achieving reductions in carbon emissions required in the Kyoto Protocol.[10] There are a number of cases considered in this analysis that vary assumptions regarding trading of carbon permits, carbon sinks, and carbon offsets. These assumptions result in different levels of the carbon fee and cause the costs of providing electricity from fossil-fired plants to vary. As a result the economic test used to determine the operating lives of existing nuclear plants results in different levels of retirements of nuclear capacity. Figure 1 show the levels of nuclear capacity that result. Nuclear capacity ranges from 48 to 86 gigawatts in 2020 for the reference case and three percent below 1990 case, respectively. This range is the result of the different carbon fees only as all other assumptions regarding nuclear power are unchanged.

In order to determine if new nuclear capacity could also help reduce carbon emissions, two sensitivity cases were analyzed[11]. In one case it was assumed that carbon emission limits could be set at 9 percent above 1990 levels in 2010 if international activities including trading of carbon permits and offsets from other greenhouse gases and forestation projects are allowed. Although this case raises the costs of generating power from fossil-fired units by incorporation of a carbon fee ($163 per ton by 2010) to the delivered price of fuel, the increases are not sufficient to overcome the difference in costs between new nuclear capacity and fossil-fueled technologies. As a result, there are no new nuclear plants built through the year 2020 in this case.

In the second sensitivity case, a more stringent target of 3 percent below 1990 levels was set for carbon emissions eliminating the carbon permits in international markets but allowing credit for sinks and offsets. For this sensitivity test it was assumed that the initial nuclear units could be constructed without the cost premium typically associated with new designs. The basis for this assumption is that vendors would be willing to build plants at a fixed price in order to be competitive with other providers and to gain a market share.

Under these assumptions, about 40 gigawatts of nuclear power are constructed, mostly between 2015 and 2020. The use of fossil fuels declines compared with a case where the same emissions

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[9]It is assumed that there is no uncertainty in costs quoted before a new design is built and, if costs exceed the original estimate, they are not passed on to the plant owner. The costs used under this assumption are those that would be expected for the fifth unit constructed under reference case assumptions. The cost of the fifth unit is assumed to be that of a mature technology where uncertainties in cost estimates have been eliminated.

[10] For a description of the protocol and analysis see Energy Information Administration, *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity,* SR/OIAF/98-03 (Washington, DC, October 1998).

[11]These sensitivity cases are compared with the reference case used in the Kyoto analysis. The Kyoto reference case, although similar, is not the same as the reference case used in the *Annual Energy Outlook 1999* because of differences in assumptions regarding technological improvements and costs. The differences are discussed in Energy Information Administration, *Impacts of the Kyoto Protocol on U. S. Energy Markets and Economic Activity*, SR/OIAF/98-03 (Washington, DC, October 1998), Appendix A. The assumptions regarding the operating lives of nuclear plants are the same as those used in the *Annual Energy Outlook 1999.*

targets are assumed but without the option for new nuclear generators. Total fossil fuel consumption declines by 1 quadrillion Btu or 6 percent when new nuclear plants are built. In addition, even though consumers are projected to increase their use of electricity by one percent above the case where new nuclear power is excluded, there is a drop in the price of electricity. Average electricity prices to consumers decline by 4 mills per kilowatt hour (4 percent) compared with the case without new nuclear power. The addition of new nuclear power plants results in reductions in the cost of a carbon allowance. The price for an allowance would decline from $245 to $203 per metric ton of carbon (1996 dollars) in 2020[12]. It is also interesting to note that slightly less existing nuclear capacity would be economic to operate in 2020 (about 2 gigawatts) because the lower cost of the carbon permit causes fossil-fired plants to be more competitive with nuclear plants.

These results indicate the potential for nuclear power in a carbon constrained environment. However, the case does not address the impacts of developing the supporting infrastructure for nuclear power that would be required to permit the rapid expansion that these results suggest. If costs associated with new infrastructure are required, then there could be less penetration of new nuclear capacity than projected in this case.

CONCLUSIONS

Nuclear power which currently provides 18 percent of electricity supply is expected to drop to 7 percent by 2020 as existing plants retire and no new plants are built. Some existing plants will retire before the end of their operating licenses due to performance problems and age related investment requirements. New plants are not expected to be built because high capital costs make them non-competitive with other technologies and because permanent storage for waste is not available. The reduced contribution of nuclear power in the future increases consumption of fossil fuels and increases carbon emissions. If aging and performance problems do not cause plants to be shutdown early, then the growth in carbon emissions between 1997 and 2020 could be reduced by 15 percent. If there are mandates to reduce carbon emissions to 3 percent below 1990 levels by 2010 and thereafter, then nuclear power plants would be economic to build starting about 2015, given that vendors offer firm prices for construction.

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Table1 Cost of Producing Electricity from New Plants

	Pulverized Coal		Advanced Combined-Cycle		Advanced Nuclear	
1996mills/kWh	2010	2020	2010	2020	2010	2020
Capital	24.21	24.95	6.24	6.32	33.81	35.05
Fixed O&M	3.18	3.18	1.97	1.97	7.79	7.79
Fuel	10.09	9.55	22.13	23.54	3.74	3.86
Total	37.48	37.67	30.34	31.83	45.34	46.70

Note: Costs calculated on 80 percent capacity factor; Variable O&M included in fuel component. The cost for the advanced nuclear unit is for a mature technology which is assumed to occur when the fifth unit is constructed.

[12]Although it is assumed that carbon reduction targets must be met by 2010, there are no nuclear units constructed by then and there is no change in the carbon permit price.

Figure 1 Projections of Nuclear Capacity, 2000-2020